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PROGRAM TOMSCAT

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ABSTRACT

Program TOMSCAT is an interactive code that calculates the scattering spectrum and background for a Thomson-scattering diagnostic in typical magnetic fusion plasmas. Thomson scattering yields values of the plasma electron temperature T_e and electron density N_e. This program is intended as an aid for designing Thomson-scattering systems, so all experimental parameters are input by the user. The code is operational on OCTOPUS. Contact the author for further information.

THOMSON-SCATTERING CALCULATION

The program evaluates the relativistically corrected power spectrum for incoherent electron scattering perpendicular to the polarization vector of a laser beam.

The form of the power spectrum was derived by Goodman[1] by carrying the angular dependence through the derivation of Mattioli and Papoular.[2] The angular dependence agrees with the form derived by Sheffield[3] in the nonrelativistic limit. The number of photons scattered into a given solid angle $\Delta\Omega$ in a unit wavelength interval $d\lambda$ is

$$P(\lambda)\, d\lambda = \Delta\Omega \; \frac{d\lambda}{\lambda} \, r_0^2 \; \frac{N_e}{\sqrt{2\pi}\, \sin(\theta/2)} \, \Delta Z \, \frac{P_L \lambda_L}{hc} \, Y_1 \, \frac{c}{V} \exp\left[-\left(\frac{c}{V}\right)^2 \frac{Y_2}{2 \sin^2(\theta/2)}\right] ,$$

where

$$Y_1 = \frac{1}{2}\left[1 - 3.5x + \left(7.63 - \frac{0.25}{2 \sin^2(\theta/2)}\right)x^2 - \left(13.07 - \frac{0.63}{2 \sin^2(\theta/2)}\right)x^3\right] ,$$

$$Y_2 = \frac{1}{2} X^2 (1 - X) ,$$

$$X = \frac{(\lambda - \lambda_L)}{\lambda_L},$$

λ_L = laser wavelength (nm),

λ = scattered wavelength (nm),

$$v\ (m/s) = \frac{(2kT_e)^{1/2}}{m_e} = 5.93 \times 10^5\ (T_e(eV))^{1/2},$$

h = Planck's constant,

c = speed of light,

$$r_0 = \frac{e^2}{m_e c^2} = 2 \times 10^{-13}\ \text{cm (classical electron radius)},$$

ΔZ = length of observed scattering volume (cm),

P_L = laser energy (J),

$\Delta\Omega$ = solid angle of observation,

N_e = local electron density (cm^{-3}),

T_e = local electron temperature (eV),

and

θ = scattering angle.

The equation is evaluated to yield the number of photons per nanometer entering the aperture of the collection optics. A user-definable optical transmission constant is available to permit calculation of the number of photons per nanometer incident on the detector. Planned improvements to the code include the addition of detector-response spectra and the addition of a multi-channel integration package to permit calculation of actual system responses.

Figure 1 shows Thomson-scattering spectra, for several electron temperatures, generated by TOMSCAT using constant system transmission and detector response factors.

The validity of limiting the calculation to incoherent electron scattering was established by Salpeter[4] for cases in which the scattering scale length is less than the Debye length λ_D. The ratio of the scale and Debye lengths, called the scattering parameter α, is given by

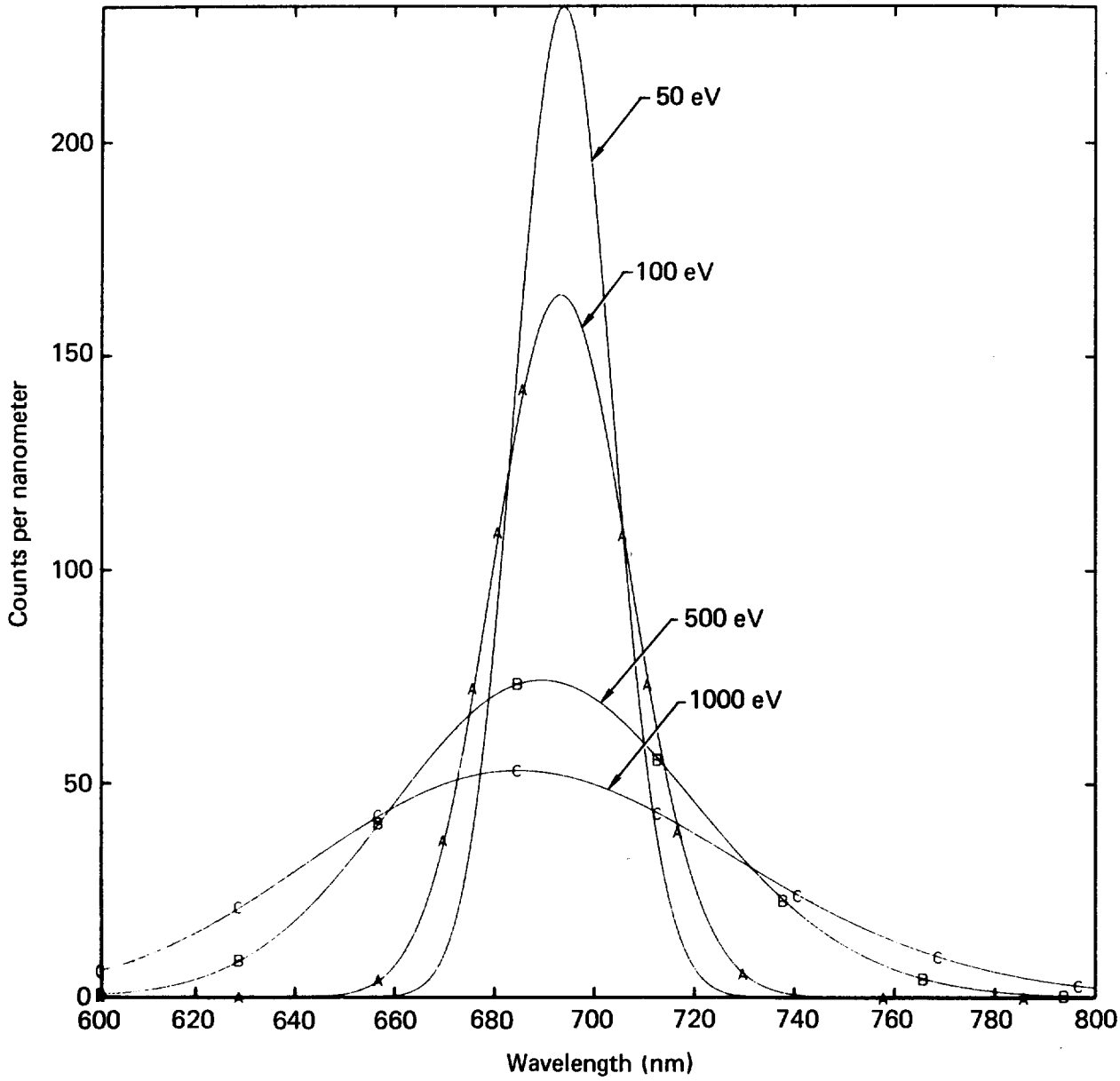

FIG. 1. Computed Thomson-scattering spectra for TMX for various electron temperatures at constant electron density $N_e = 1.0 \times 10^{12}$ cm^{-3}.

$$\alpha = \frac{\lambda_L}{4\pi\ \lambda_D \sin(\theta/2)} = 1.58 \times 10^{-13}\ \lambda_L \left[\frac{N_e}{T_e\ (1 - \cos\theta)}\right]^{1/2}.$$

The program calculates α and prints its value in the teletype case summary. If $\alpha > 0.1$ for a given case, a warning will be printed questioning the validity of the model.

BACKGROUND CALCULATION

One section of the code calculates a background bremsstrahlung power spectrum. The expression for the number of photons emitted per cubic centimeter per second $E(\lambda)d\lambda$ (taken from Lochte-Holtgreven[5]) is

$$E_\lambda\ d\lambda = 1.9 \times 10^{-37}\ \frac{N_e N_i\ \bar{g}\ Z_{eff}^2}{hc\lambda T_e} \exp\left[\frac{-1239.5}{\lambda T_e}\right] d\lambda\ .$$

To evaluate this expression, we assume that the electron and ion densities N_e and N_i are equal. Using the Born approximation, Hughes[6] obtained the following expression for the Gaunt factor $\bar{g}$:

$$\bar{g}(\lambda, T_e) = \frac{\sqrt{3}}{\pi} \ln\left(3.598 \times 10^{-19}\ \frac{\lambda T_e}{hc}\right).$$

In both the above equations, the constants have been adjusted so λ is in nm and T_e is in eV.

A user-definable enhancement factor Z_{eff}^2 is included to account for the additional radiation due to impurities and recombination. The absolute intensity of the background is typically 5 to 100 times that expected for hydrogen bremsstrahlung.[7] This additional radiation is strongly dependent on machine cleanliness, and varies substantially during a run cycle. At Culham, Forrest et al.[8] used an enhancement factor of 100 in their studies for JET.

The number of background photons $P_b(\lambda)d\lambda$ collected by the Thomson-scattering system is given by

$$P_b(\lambda)\, d\lambda = \Delta V\, \Delta t\, \frac{\Delta\Omega}{4\pi}\, E_\lambda d\lambda \ .$$

The collection volume ΔV is the entire light-emitting region seen by the optics; its magnitude is estimated by multiplying the area of the entrance slit (as imaged in the plasma) by the diameter of the plasma. The integration time Δt is the length of the laser pulse, if an ocilloscope is used to record the data, or the gate time, if an integrator is used. If a polarizer is used in the collection optics, the background radiation is divided by two.

The effects of spectral line radiation are neglected in this analysis, because not enough is known about what lines are present or their intensities. Major lines such as Hα are typically excluded from the collection optics. Experience on TMX[1] indicates that impurity lines are occasionally a significant problem, but that their effects are quite dependent on machine conditions.

Figure 2 is a comparison of a TOMSCAT calculation and TMX data (shot 36, 27 November 1979), showing the effects of spectral lines. The data plotted in Fig. 3 represent a proposed Thomson-scattering system for MFTF, and illustrate the importance of the background enhancement factor in such measurements.

PROGRAM OPERATION

Access to the program is by running TOMSCAT. All inputs are user-definable from the teletype. The user must input at least the first values of T_e and N_e; all other variables are optionally definable. If undefined, these variables are set to default values or to the values established in the previous case. Default values are given in Table 1.

The Thomson-scattering spectrum is output as a survivable file labeled SCATFILEn, where n is the file designator. The designators are the elements of the character set, taken in order. Files are not written over even if the program is terminated and restarted. A case summary, with the filename, is output to the teletype.

The user may also choose to produce a background spectrum, which is output to a file labeled BKNDFILEn. The file designator n will be the same as that for the scattering file for which it computed. A background summary is

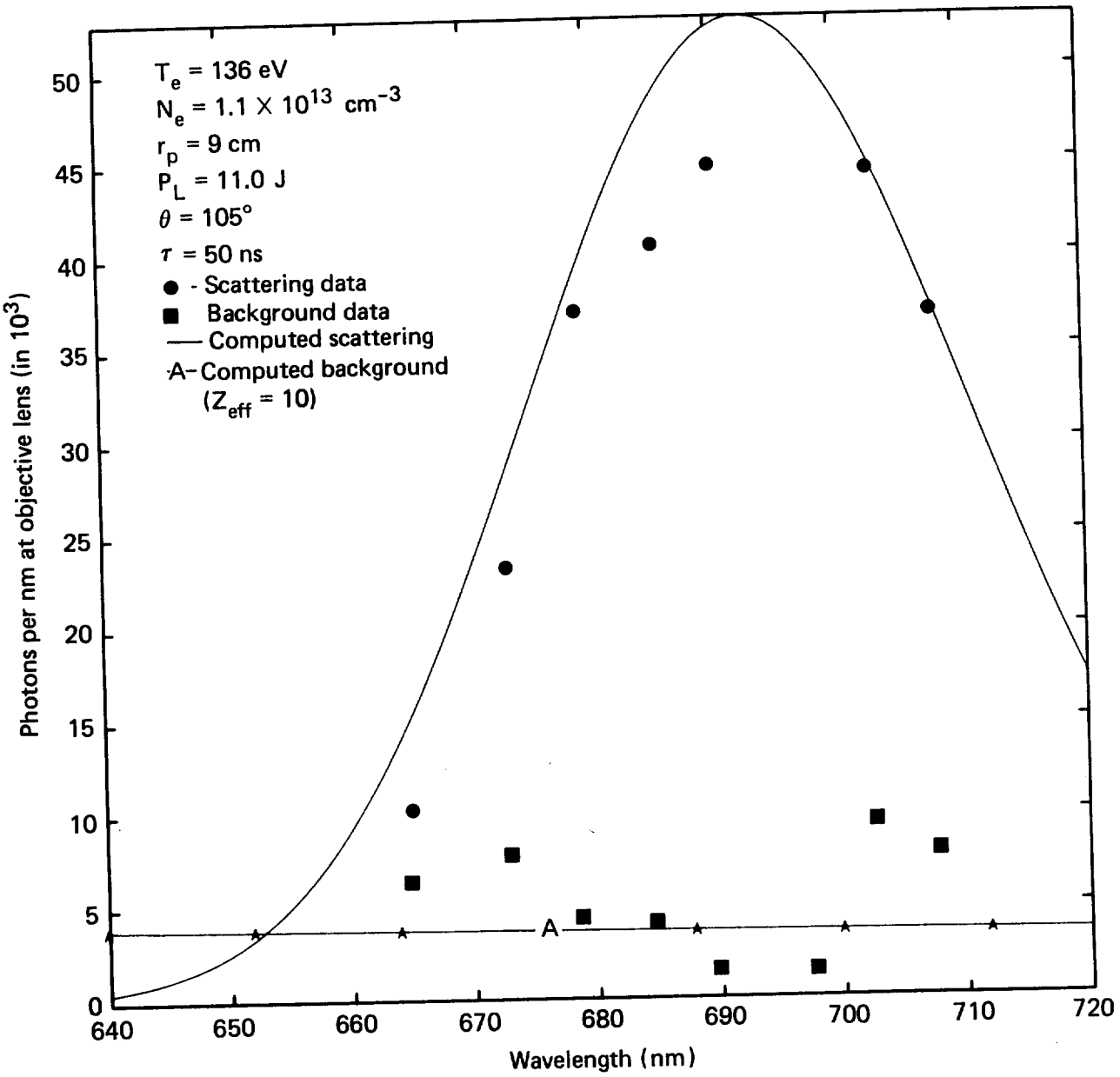

FIG. 2. Thomson-scattering spectrum and background from TMX, and corresponding TOMSCAT computation.

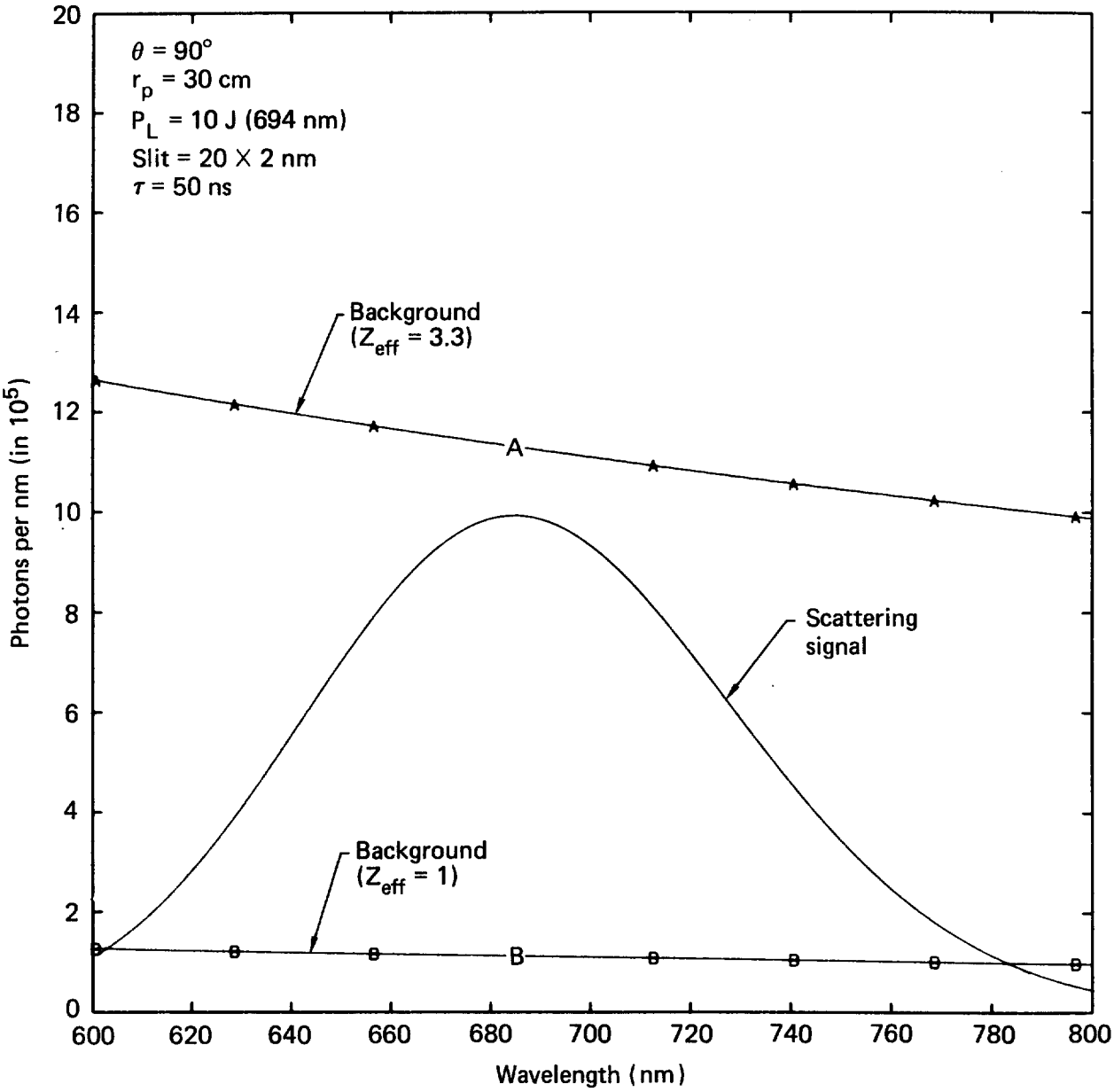

FIG. 3. Computed scattering and background spectra for MFTF with T_e = 1 keV and $N_e = 4 \times 10^{14}$ cm^{-3}.

TABLE 1. Input default values of parameters in TOMSCAT.

Parameter	Default value
Scattering calculation	
Scattering angle	90.0 deg
Laser wavelength	694.3 nm
Laser energy	1.0 J
Lamda min	600.0 nm
Lamda max	800.0 nm
Increment	1.0 nm
F-number	6.0
System transmission	1.0
Length of collection volume	1.0 cm
Calculate background	"NO"
New case	"NO"
Background calculation	
Diameter of plasma	60.0 cm
Impurities enhancement	100.0
Entrance slit	2.0 mm
Integration time	50.0 ns
Polarizer	"NO"

output to the teletype. Output files are compatible with the plotting code SOCKITTOME.[9] Figures 1-3 are SOCKITTOME plots.

INPUT PARAMETERS

Parameter inputs are prompted by the program with specific requests to the teletype. All input parameters are in floating-point (F) format except electron density N_e, which is in exponential (E) format. Each input requires a decimal point and is terminated by a comma. Questions are answered

by alphanumeric YES or NO inputs. A zero in a field, or a RETURN with no input, automatically inputs the default value or the previous value if any.

The parameters TE and NE are the electron temperature and density, respectively. These have no default values, and must be entered for the first case. NE is input in E format, and a comma is required after the exponent. The wavelength limits and increment establish the limits of the computed spectrum. All other inputs are self-explanatory. Buffer lengths are sufficient to allow up to 1000 points to be calculated and are protected against overflow.

ACKNOWLEDGMENTS

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